OPPORTUNITIES FOR PETROLEUM COKE GASIFICATION UNDER TIGHTER SULFUR LIMITS FOR TRANSPORTATION FUELS

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INTRODUCTION

As refiners are pushed towards producing cleaner, lower sulfur transportation fuels from poorer quality crudes, petroleum coke could be used as a source of hydrogen. Hydrogen will be in great demand as the Tier 2 sulfur regulations limiting sulfur in gasoline to 30 ppm and sulfur in diesel to 15 ppm take effect. Petroleum coke could also be used to produce refinery power and excess power could be sold. In a deregulated electric power industry, refiners may choose to become power providers. Other products can also be produced once the petroleum coke is converted via gasification into clean synthesis gas. These other products could include Fischer-Tropsch (F-T) liquids. F-T liquids are zero sulfur, paraffinic hydrocarbons that can be classified as ultra-clean transportation fuels. Zero sulfur, high cetane F-T diesel could be used as a blending stock to assist refiners in meeting ultra low sulfur diesel specifications.

CURRENT AND FUTURE U.S. REFINERY SITUATION

The Oil and Gas Journal publishes a complete list of U.S. refineries every year.[1] This was used to identify all U.S. refineries producing more than 1000 tons per day of pet coke. In total, 35 refineries were identified. Most of these are in California (10 refineries) followed by Texas (8) and Louisiana (6). A total of almost 95,000 tons per day of petroleum coke is produced in these 35 refineries. Total U.S. coke production for that year was 96,200 tons therefore these refineries represent over 98 percent of production. Based on total crude capacity this production of coke is equivalent to 12.5 tons per thousand barrels per day. The actual feed to the cokers was 1.6 million barrels per day (MMBPD) to give an average coke yield of about 57 tons per thousand barrels feed.

In order to estimate the U.S. refinery situation in the year 2010 it was necessary to make some assumptions. It was first assumed that demand for petroleum continues to increase at a rate of 1.2 percent per annum to 2010. This assumption is taken from the Energy Information Administration Annual Energy outlook for 1999.[2] Further, it was assumed that by 2010 all gasoline and diesel produced by U.S. refineries will have a sulfur content of less than 30 ppm. Desulfurization of gasoline and diesel to these low levels will require extensive hydrotreating of both catalytic cracker feed and product and of distillate.

Mitretek has developed a refinery simulation model that estimates the hydrogen required and costs of this desulfurization. The results of this model show that an average 150,000 barrel per day (BPD) refinery will require an additional 38 MMSCFD of hydrogen to produce gasoline and diesel with a sulfur content of less than 30 ppm. This is equivalent 0.25 MMSCFD per 1000 BPD. For California the situation with respect to hydrogen is different. California is currently already producing gasoline that is low in sulfur under the Phase 2 gasoline regulations. Because of these regulations it is assumed that California refiners will require considerably less hydrogen to produce both gasoline and diesel with less than 30 ppm sulfur. In this analysis it is assumed that California refineries will only need one third of the hydrogen compared to refiners in the rest of the country, that is 0.0825 MMSCFD per 1000 BPD.

Other assumptions were that a 230,000 BPD refinery will consume, on average, 100 MW of power and that future coke production as a function of coker feed remains unchanged.

To estimate the economic impacts in this analysis it is necessary to assign values to both electric power and to hydrogen. It is assumed that the value of electricity is determined by the cost of producing it from an advanced natural gas combined cycle (NGCC) plant. Advanced NGCC is assumed to have an installed capital cost of $494 per kilowatt and a heat rate of 6,396 Btu per kWh. Based on these assumptions the required selling price of the electricity would be given by the following equation:

$$\text{Electricity in \$/kWh} = 0.0064 * \text{NG cost in \$/MMBtu} + 0.0116$$

For hydrogen, the value is assumed to be equal to the cost of producing hydrogen from new steam reforming facilities. It is assumed that a new hydrogen plant to produce 60 MMSCFD of hydrogen would cost $90 million. Based on this the required selling price of hydrogen would be given by:

$$\text{Hydrogen cost in \$ per MSCF} = 0.45 * \text{NG cost in \$/MMBtu} + 0.76$$

For example if NG were $2.75 per MMBtu then hydrogen would be $2 per MSCF.

Based on the above assumptions, it is estimated that in 2010 forty refineries will produce sufficient petroleum coke to warrant installation of pet coke gasification facilities. Because of the increase in petroleum consumption by 2010 there is estimated to be over

116,000 tons per day of coke produced. Hydrogen demand in these refineries is estimated to increase to about 4.4 BSCFD compared to just over 2 BCFD in 1999.

SINGLE PLANT ANALYSIS

This analysis considers the case of a single pet coke conversion facility located at a generic refinery. The plant gasifies 2,700 tons per day of pet coke using Texaco oxygen-blown gasification. Pet coke in 2010 is priced at $10 per ton based on future price estimates made by the WEFA Energy Group. The additional hydrogen required for this generic refinery is assumed to be 60 MMSCFD, and electric power required is assumed to be 100 MW. The value of the hydrogen and electric power produced is given by the equations shown above.

Four configurations were analyzed in this analysis. These were:

- Petroleum coke to electric power
- Petroleum coke to power and Fischer-Tropsch fuels
- Petroleum coke to hydrogen and power
- Petroleum coke to hydrogen and Fischer-Tropsch fuels

The primary conversion process is the gasification of the pet coke to a raw synthesis gas. The overall raw syngas efficiency is 75 percent, that is 75 percent of the heating value of the pet coke on an HHV basis is available in the raw syngas. For the power production configuration, a single train of Texaco gasification and air separation is used. The raw syngas is cleaned using an acid gas removal (AGR) system, and the clean gas is sent to a combined cycle power block, consisting of a gas turbine, a heat recovery steam generator (HRSG), and a steam turbine. From an input of 2700 tons per day of pet coke, the net power produced (after parasitic plant power for air separation) is 374 MW, equivalent to an overall efficiency of 41.7 percent on a HHV basis. The capacity factor for this configuration is assumed to be 85 percent.

For the configuration that produces both power and F-T liquid transportation fuels, again a single train gasification system is used. The raw syngas is cleaned in an AGR system and polished to ultra-low sulfur levels and then sent to a slurry-phase F-T process. The F-T process is operated in a once-through mode and, after liquid product separation, the tail gas containing unconverted gas, light hydrocarbons and carbon dioxide is used as fuel to superheat the steam produced in gasification and synthesis. This superheated steam is then fed to a steam turbine for power production. Steam superheat is used because there is insufficient tail gas to fire a gas turbine. In this configuration 2,700 TPD of pet coke can produce 88 MW of electric power and 5,800 BPD of essentially naphtha and diesel boiling range liquid fuels. The liquid products are a combination of straight run material and hydrocrackate resulting from the cracking of the F-T wax. The overall plant efficiency is 51.8 percent HHV. The capacity factor for this configuration is assumed to be 85 percent.

For the configuration that produces both hydrogen and power, two gasification trains are used to provide high availability for hydrogen production. Hydrogen availability is estimated to be 96 percent using this two-train configuration. The raw syngas is split into two steams. One of these streams is shifted using raw gas shift and the shifted gas is cleaned and sent to PSA units for recovery of hydrogen. The other stream is cleaned in an AGR unit and sent to a combined cycle power block that includes a gas turbine, HRSG, and steam turbine. This configuration produces the required 60 MMSCFD of hydrogen for the refinery and 238 net MW of power. Overall efficiency for this configuration is 53.5 percent HHV. During gasifier shutdown, supplemental natural gas is purchased to maintain a capacity factor of 85 percent for power generation.

The final configuration investigated in this analysis is a combined facility that produces the refinery hydrogen requirement and F-T liquid fuels. In this two-train gasifier configuration, the raw syngas stream is split, and one of the streams is used to produce hydrogen as described above. The other stream is cleaned and sent to a slurry F-T reactor in a once through mode of operation. The liquid product is separated, the wax is hydrocracked, and the F-T tail gas is used to fire a superheater to superheat the available steam for feed to a steam turbine for power production. This configuration produces 60 MMSCFD of hydrogen, 3,700 BPD of F-T fuels, and about 35 MW of excess power. Overall efficiency is 58 percent HHV. The hydrogen availability is 96 percent and the capacity factor for the F-T fuels is estimated to be 75 percent.

Table 1 summarizes the capital costs of these four configurations.

Table 1. Capital Cost Summary for Petroleum Coke Conversion Facilities

Product	Capital Cost $MM	Power MW	Liquids BPD	Hydrogen MMSCFD	Efficiency (% HHV)
Power	464	374	0	0	41.7
F-T/Power	382	88	5,800	0	51.8
Hydrogen/Power	481	238	0	60	53.5
Hydrogen/F-T	424	35	3,700	60	58.0

The financial assumptions used in this single plant analysis are given below. These were used to calculate the return on equity (ROE) for these plant configurations as a function of natural gas price for various world oil price (WOP) scenarios.

- 25 Year Plant Life
- 67/33 Debt Equity Financing
- 8% Interest, 16 Year Term
- 3% Inflation
- 16 Year DDB Depreciation
- 40% Combined State and Federal Tax Rate

Figure 1 shows the ROE plotted against the world oil price for the four configurations described above. It is assumed that the natural gas price and WOP are related by the simple equation:

Natural gas price (\$/MMBtu) = 0.13*WOP (\$/BBL)

Thus, if the WOP were \$25 per barrel the price of natural gas would be \$3.25/MMBtu.

Because of their exceptional quality, F-T liquids were assumed to command a premium value over crude oil of \$5 per barrel.

Figure 1 shows that, if the WOP is \$25 per barrel (equivalent to natural gas at \$3.25/MMBtu) or higher, ROEs of about 15 percent can be realized for all four configurations. The two configurations that coproduce hydrogen give higher ROEs than the power only and F-T plus power configurations.

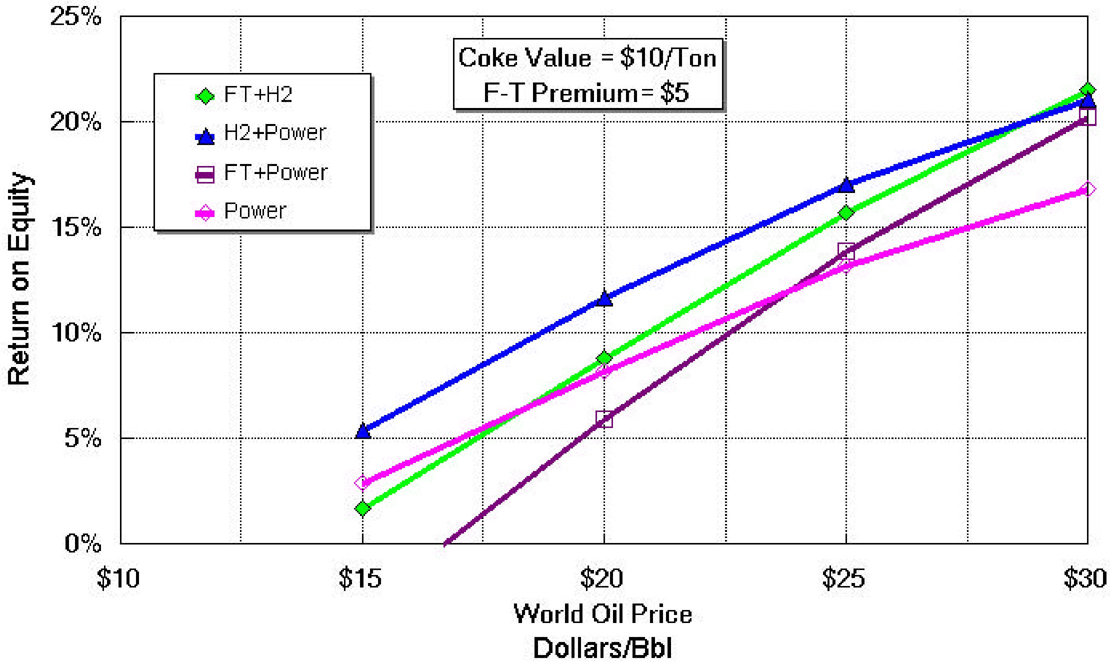
CONCLUSIONS

This analysis has investigated the potential for petroleum coke conversion at a generic refinery to produce a combination of products including hydrogen, electric power, and ultra-clean F-T liquid fuels. With the Environmental Protection Agency Tier 2 regulations pending, refineries will require additional hydrogen to hydrotreat and hydrocrack feeds to produce gasoline and diesel fuels with less than 30 ppm of sulfur. This analysis indicates that pet coke could be a candidate feedstock for hydrogen production, especially if refiners have to pay in excess of \$3.25/MMBtu for natural gas as steam reformer feed and oil prices stay above \$25 per barrel. However, hydrogen availability is an important issue and refiners must be persuaded that gasification will prove to be as reliable a technology in the future as natural gas steam reforming is today.

Many refineries produce sufficient pet coke to more than satisfy refinery hydrogen requirements. This would allow coproduction of hydrogen and power or F-T liquids. Many of these coproduction options look economically attractive when oil prices are above \$25 per barrel or gas prices are above \$3.25/MMBtu provided that the performance and cost estimates derived in this analysis can be substantiated in commercial practice.

Coproducing ultra-clean F-T liquids as blending stocks for ultra-low sulfur fuels production could be a viable option for refiners in the future if the WOP remains in the range of \$25-\$30/bbl. Thus, pet coke that is often of poor quality and low value could become an important feedstock for a refiner to produce not only his own hydrogen and power needs, but also to produce F-T blending stocks and power for export.

Figure 1. Return on Equity Versus WOP if Natural Gas Price is Related to World Oil Price



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